

0310000000-Cook
Chicago/Illinois Smelting & Refining
ILD982074718

Med - HSW
3/16/90

560301-AD102

CERCLA Preliminary Assessment Report



Illinois Environmental
Protection Agency
P.O. Box 19276,
Springfield, IL 62794-9276

EPA Region 5 Records Ctr.



331354

LPC #0310000000 -- Cook
Chicago/Illinois Smelting and Refining Company
ILD982074718

EXECUTIVE SUMMARY

The Illinois Smelting and Refining Company was placed on CERCLIS on January 29, 1988 as a result of a request for discovery notice from the state of Illinois. This site was one of fifteen Chicago area sites which was discovered in an Agency review of potential hazardous waste areas, utilizing early 1900 fire insurance maps.

The Illinois Smelting and Refining Company operated a general metals smelting and refining facility at 410 North Peoria, Chicago, Illinois in the late 1800s and early 1900s. The actual dates of operation at this site are unknown. However, records indicate the Illinois Smelting and Refining Company was incorporated on October 25, 1888. Mr. Albert Haas, a former Registered Agent for the company was not aware of when operations at this location may have begun or ceased. A Sanborn Insurance Map developed in the early 1900s indicates the Illinois Smelting and Refining Company to be operating at the Peoria Street location.

Additionally, the insurance map also indicates that two kettles were located at the site. It is believed these kettles were likely for the refining of metals. Although incorporation documents indicate the object of the company was general smelting and refining, it is believed that lead, due to its low melting point, was the predominate metal refined. It is also suspected that the Parkes process of refining was used since kettles were present. In the Parkes process kettles and reverberatory furnaces were used to remove metallic contaminants such as copper, antimony, arsenic, gold, silver and zinc from lead bullion. However, since reverberatory furnaces were not indicated as being present in the insurance map, it is suspected that refining of secondary lead may have been the predominate operation performed. On the basis of the above, lead is likely the only heavy metal potentially present.

Agency representatives conducted a reconnaissance inspection of this site on September 1, 1989. The site is approximately 0.5 acres (100' x 200') in size. All structures that were indicated as being present in the insurance map have now been demolished. There are no structures on the site now. It appears that in removing the structures and earthened ledge covered with concrete was exposed at the west and south sides of the site. This ledge is now eroding into the site. The site surface is barren soil with some intermixed gravel. It is currently being used by the Speedman Refuse Company to store refuse roll-off boxes. The site is completely fenced and has a lockable gate to restrict access. However, at the time of the reconnaissance inspection the gates were open, work personnel were on site only intermittently and there were no security personnel on site.

There are no surface water impoundments on site and surface water drainage is by city storm sewers. No groundwater users or surface water intakes were found within the area of the concern.

The site is bound on the north by the Midwest Barrel building and on the east by Peoria Street and a vacant lot. Kinzie Street and an abandoned railroad viaduct is located south of the site. The Salisbury Rubber Company and Sangamon Avenue are located to the west of the site.

A medium priority for a screening site inspection has been assigned to this site due its potential direct contact hazard to the surrounding population. There is no groundwater use or surface water intakes in the area of concern.

BC/mls/3184k/59-60



POTENTIAL HAZARDOUS WASTE SITE
PRELIMINARY ASSESSMENT
PART 1 - SITE INFORMATION AND ASSESSMENT

I. IDENTIFICATION

01 STATE 02 SITE NUMBER

IL D982574-713

II. SITE NAME AND LOCATION

01 SITE NAME (Legal, common, or descriptive name of site)

ILLINOIS SMELTING + REFINING

02 STREET, ROUTE NO., OR SPECIFIC LOCATION IDENTIFIER

410 NORTH PEORIA

03 CITY

CHICAGO

04 STATE

05 ZIP CODE

06 COUNTY

07 COUNTY CODE

08 CONG DIST

IL

60622

COOK

031

08

09 COORDINATES LATITUDE

LONGITUDE

41 53 23.0 N

087 32 00.0 W

10 DIRECTIONS TO SITE (Starting from nearest public road)

410 NORTH PEORIA (SEE MAP)

III. RESPONSIBLE PARTIES

01 OWNER (if known)

SAM V. SCARBINE

02 STREET (Business, mailing, residential)

412 N. PEORIA

03 CITY

CHICAGO

04 STATE

05 ZIP CODE

06 TELEPHONE NUMBER

IL

60602

()

07 OPERATOR (if known and different from owner)

ILLINOIS SMELTING + REFINING

08 STREET (Business, mailing, residential)

3637 SOUTH ALBANY

09 CITY

CHICAGO

10 STATE

11 ZIP CODE

12 TELEPHONE NUMBER

IL

60632

312

376-1733

13 TYPE OF OWNERSHIP (Check one)

☒ A. PRIVATE

☐ B. FEDERAL:

(Agency name)

☐ C. STATE

☐ D. COUNTY

☐ E. MUNICIPAL

☐ F. OTHER:

(Specify)

☐ G. UNKNOWN

14 OWNER/OPERATOR NOTIFICATION ON FILE (Check all that apply)

☐ A. RCRA 3001 DATE RECEIVED: MONTH DAY YEAR

☐ B. UNCONTROLLED WASTE SITE (CERCLA 103 c) DATE RECEIVED: MONTH DAY YEAR

☒ C. NONE

IV. CHARACTERIZATION OF POTENTIAL HAZARD

01 ON SITE INSPECTION

☒ YES

DATE

2/1/88

☐ NO

BY (Check all that apply)

☐ A. EPA

☐ B. EPA CONTRACTOR

☒ C. STATE

☐ D. OTHER CONTRACTOR

☐ E. LOCAL HEALTH OFFICIAL

☐ F. OTHER:

(Specify)

CONTRACTOR NAME(S):

02 SITE STATUS (Check one)

☐ A. ACTIVE

☒ B. INACTIVE

☐ C. UNKNOWN

03 YEARS OF OPERATION

BEGINNING YEAR

ENDING YEAR

☒ UNKNOWN

04 DESCRIPTION OF SUBSTANCES POSSIBLY PRESENT, KNOWN, OR ALLEGED

HEAVY METALS (TOXIC / PERSISTANT)

05 DESCRIPTION OF POTENTIAL HAZARD TO ENVIRONMENT AND/OR POPULATION

DIRECT CONTACT (POPULATION)

GROUNDWATER (ENVIRONMENT)

V. PRIORITY ASSESSMENT

01 PRIORITY FOR INSPECTION (Check one. If high or medium is checked, complete Part 2 - Waste Information and Part 3 - Description of Hazardous Conditions and Incidents)

☐ A. HIGH

(Inspection required promptly)

☒ B. MEDIUM

(Inspection required)

☐ C. LOW

(Inspect on time available basis)

☐ D. NONE

(No further action needed, complete current disposition form)

VI. INFORMATION AVAILABLE FROM

01 CONTACT

MICHAEL G. HAAS

02 OF (Agency/Organization)

ILLINOIS SMELTING + REFINING

03 TELEPHONE NUMBER

312 376 1900

04 PERSON RESPONSIBLE FOR ASSESSMENT

BRYAN CLAYTON &

05 AGENCY

IEPA

06 ORGANIZATION

REMEDIAL PROJECTS

07 TELEPHONE NUMBER

(217) 524-6712

08 DATE

2/13/88



POTENTIAL HAZARDOUS WASTE SITE
PRELIMINARY ASSESSMENT
PART 3 - DESCRIPTION OF HAZARDOUS CONDITIONS AND INCIDENTS

I. IDENTIFICATION

01 STATE 02 SITE NUMBER

IL 09827074718

II. HAZARDOUS CONDITIONS AND INCIDENTS

01 ☒ A GROUNDWATER CONTAMINATION

03 POPULATION POTENTIALLY AFFECTED: 0

02 ☐ OBSERVED (DATE: _____)

04 NARRATIVE DESCRIPTION

☒ POTENTIAL

☐ ALLEGED

HEAVY METALS MAY LEACH INTO GROUND
AND CONTAMINATE GROUNDWATER.

01 ☐ B. SURFACE WATER CONTAMINATION

03 POPULATION POTENTIALLY AFFECTED: _____

02 ☐ OBSERVED (DATE: _____)

04 NARRATIVE DESCRIPTION

☐ POTENTIAL

☐ ALLEGED

01 ☐ C. CONTAMINATION OF AIR

03 POPULATION POTENTIALLY AFFECTED: _____

02 ☐ OBSERVED (DATE: _____)

04 NARRATIVE DESCRIPTION

☐ POTENTIAL

☐ ALLEGED

01 ☐ D. FIRE/EXPLOSIVE CONDITIONS

03 POPULATION POTENTIALLY AFFECTED: _____

02 ☐ OBSERVED (DATE: _____)

04 NARRATIVE DESCRIPTION

☐ POTENTIAL

☐ ALLEGED

01 ☒ E. DIRECT CONTACT

03 POPULATION POTENTIALLY AFFECTED: 210,000

02 ☐ OBSERVED (DATE: _____)

04 NARRATIVE DESCRIPTION

☒ POTENTIAL

☐ ALLEGED

SEE PART 3, II, F BELOW

01 ☒ F. CONTAMINATION OF SOIL

03 AREA POTENTIALLY AFFECTED: 0.5
(Acres)

02 ☐ OBSERVED (DATE: _____)

04 NARRATIVE DESCRIPTION

☒ POTENTIAL

☐ ALLEGED

UNKNOWN QUANTITIES
OF HEAVY METALS MAY BE PRESENT IN THE SOIL
BE A RESULT OF SMELTING & REFINING OPERATIONS
OCCURRING ON THE SITE.

01 ☐ G. DRINKING WATER CONTAMINATION

03 POPULATION POTENTIALLY AFFECTED: _____

02 ☐ OBSERVED (DATE: _____)

04 NARRATIVE DESCRIPTION

☐ POTENTIAL

☐ ALLEGED

01 ☐ H. WORKER EXPOSURE/INJURY

03 WORKERS POTENTIALLY AFFECTED: _____

02 ☐ OBSERVED (DATE: _____)

04 NARRATIVE DESCRIPTION

☐ POTENTIAL

☐ ALLEGED

01 ☒ I. POPULATION EXPOSURE/INJURY

03 POPULATION POTENTIALLY AFFECTED: >10,000

02 ☐ OBSERVED (DATE: _____)

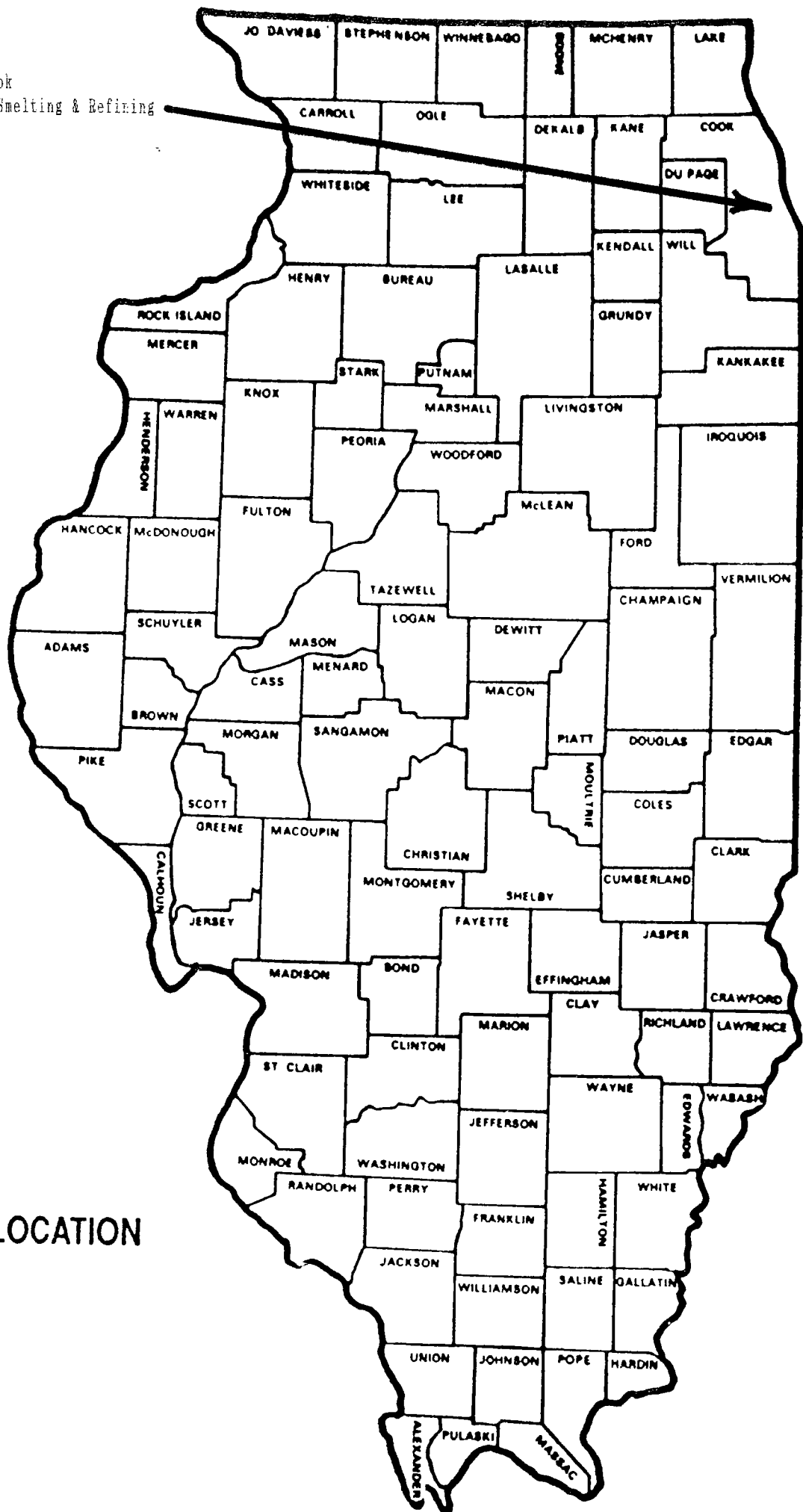
04 NARRATIVE DESCRIPTION

☒ POTENTIAL

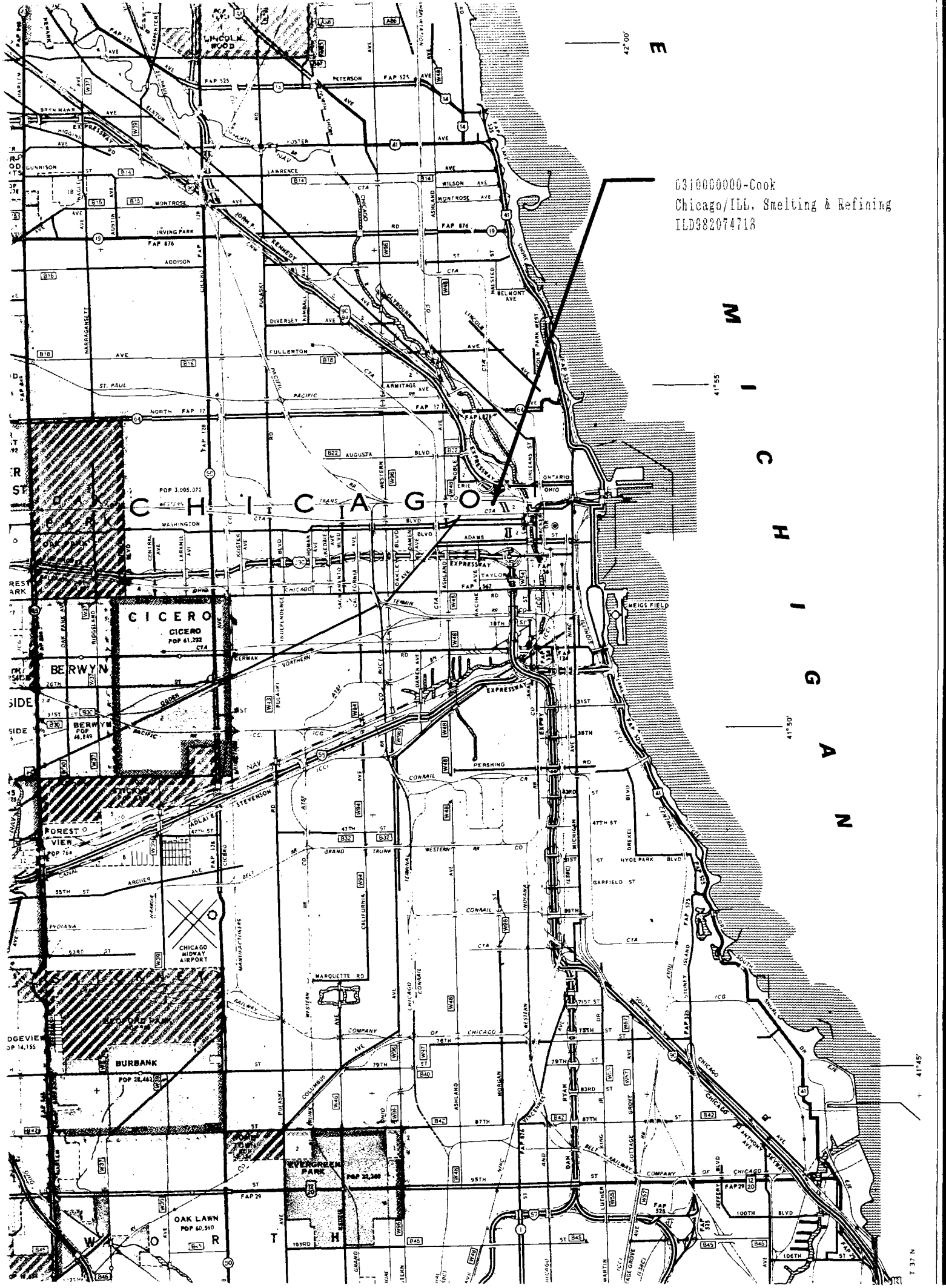
☐ ALLEGED

SITE IS FENCED BUT GATE WAS OPEN.
ALSO, SEE PART 3, II, F ABOVE.

931000000-Cook
Chicago/ILL. Smelting & Refining
TLD932074718



SITE LOCATION



0310000000-Cook
Chicago/ILL. Smelting & Refining
ILD982074718

M
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C
H
I
G
A
N

T 37 N

Date: SEP 1, 1989

Time: (A.M.) P.M.

Photograph By:

B CLAYTON

Location: LPC-0310000000

ILLINOIS SMELTING
+ REFINING Co. COOK

410 N.
PEORIA / CHICAGO, IL

Comments: Photograph taken

toward the WEST

ACROSS N. PEORIA



Date: SEP 1, 1989

Time: (A.M.) P.M.

Photograph By:

B CLAYTON

Location: LPC-0310000000

ILLINOIS SMELTING
+ REFINING Co. COOK

410 N.
PEORIA / CHICAGO, IL

Comments: Photograph taken

toward the SOUTHEAST



SEE SANBORN MAP

Date: SEP 1, 1989

Time: (A.M.) P.M.

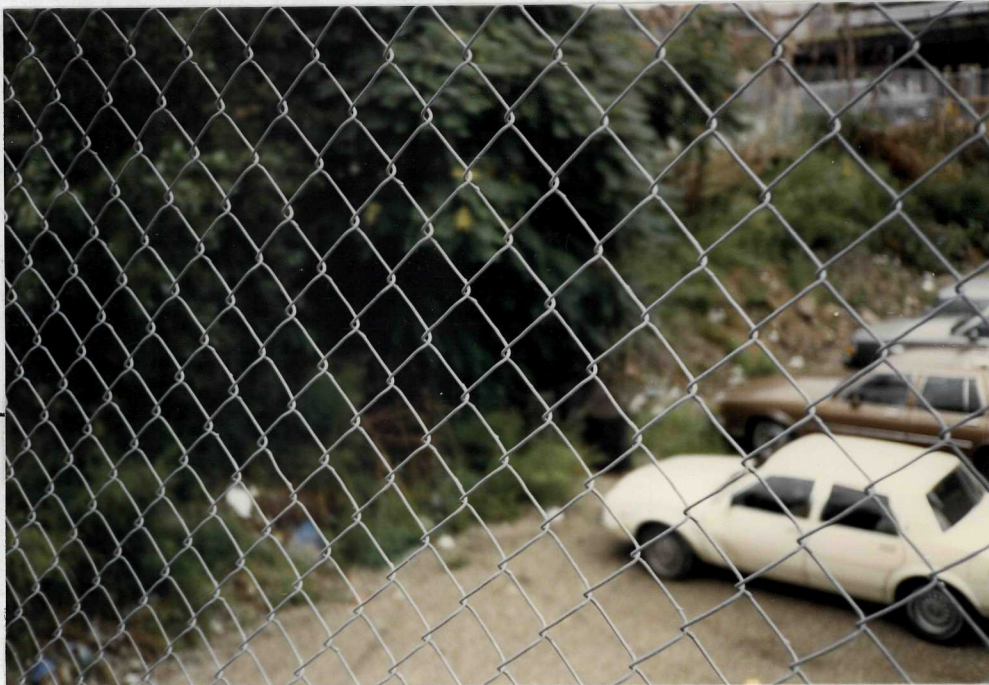
Photograph By:

B CLAYTON

Location: LPC-0310000000
ILLINOIS SMELTING
& REFINING Co. COOK
410 N.
PEORIA / CHICAGO, IL

Comments: Photograph taken

toward the NORTHWEST



Date: SEP 1, 1989

Time: (A.M.) P.M.

Photograph By:

B CLAYTON

Location: LPC-0310000000
Co. COOK
/ CHICAGO, IL

Comments: Photograph taken

toward the

NOT USED

SEE SANBORN MAP

Date: 24 Feb 88

Time: (A.M.) P.M.

Photograph By:

John Maher (5)

Location: LPC-

IL Smelting-Refining Co. Cook

410 N. Peoria / Chicago, IL

Comments: Photograph taken

toward the west on N. Peoria



Date: 24 Feb

Time: (A.M.) P.M.

Photograph By:

John Maher (6)

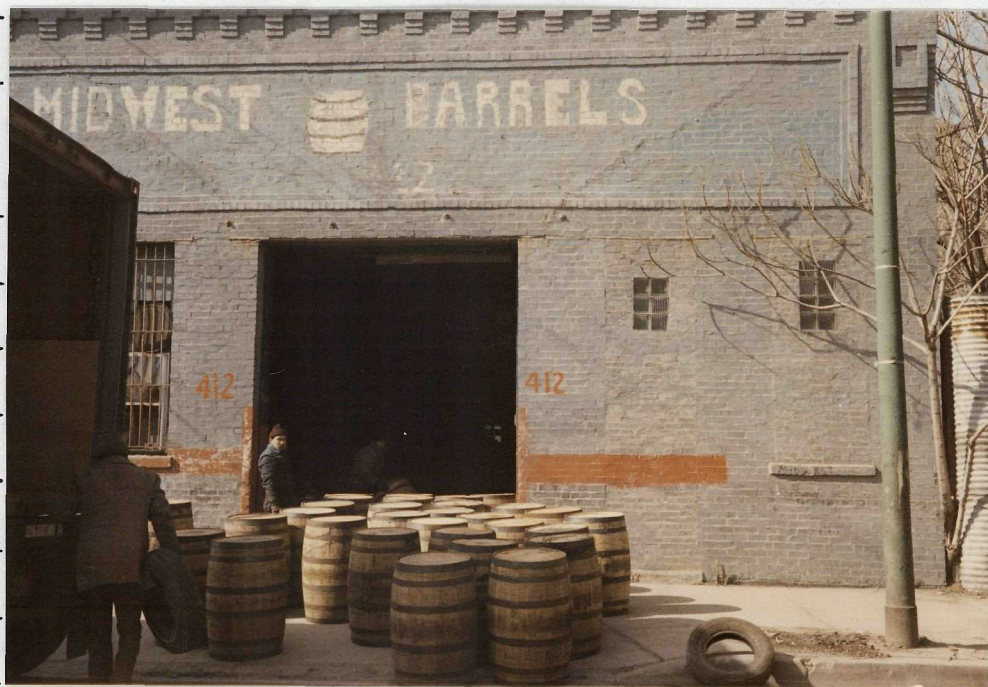
Location: LPC-

IL Smelting-Refining Co. Cook

410 N. Peoria / Chicago IL

Comments: Photograph taken

toward the west on N. Peoria



SEE SANBORN MAP

Date: 24 Feb 88

Time: (A.M.) P.M.

Photograph By:

(7)

John Maher

Location: LPC-

IL Smelting-Refining Co. Cook

410 N. Peoria / Chicago IL

Comments: Photograph taken

toward the West-Northwest

ON N. Peoria



Date: 24 Feb 88

Time: (A.M.) P.M.

Photograph By:

(8)

John Maher

Location: LPC-

IL Smelting-Refining Co. Cook

410 N. Peoria / Chicago IL

Comments: Photograph taken

toward the West ON N. Peoria



SEE SANBORN MAP

SDMS US EPA Region V

Imagery Insert Form

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Other:

0310000000-Cook

Chicago/ILL. Smelting & Refining

ILD982074718

Supporting Documentation

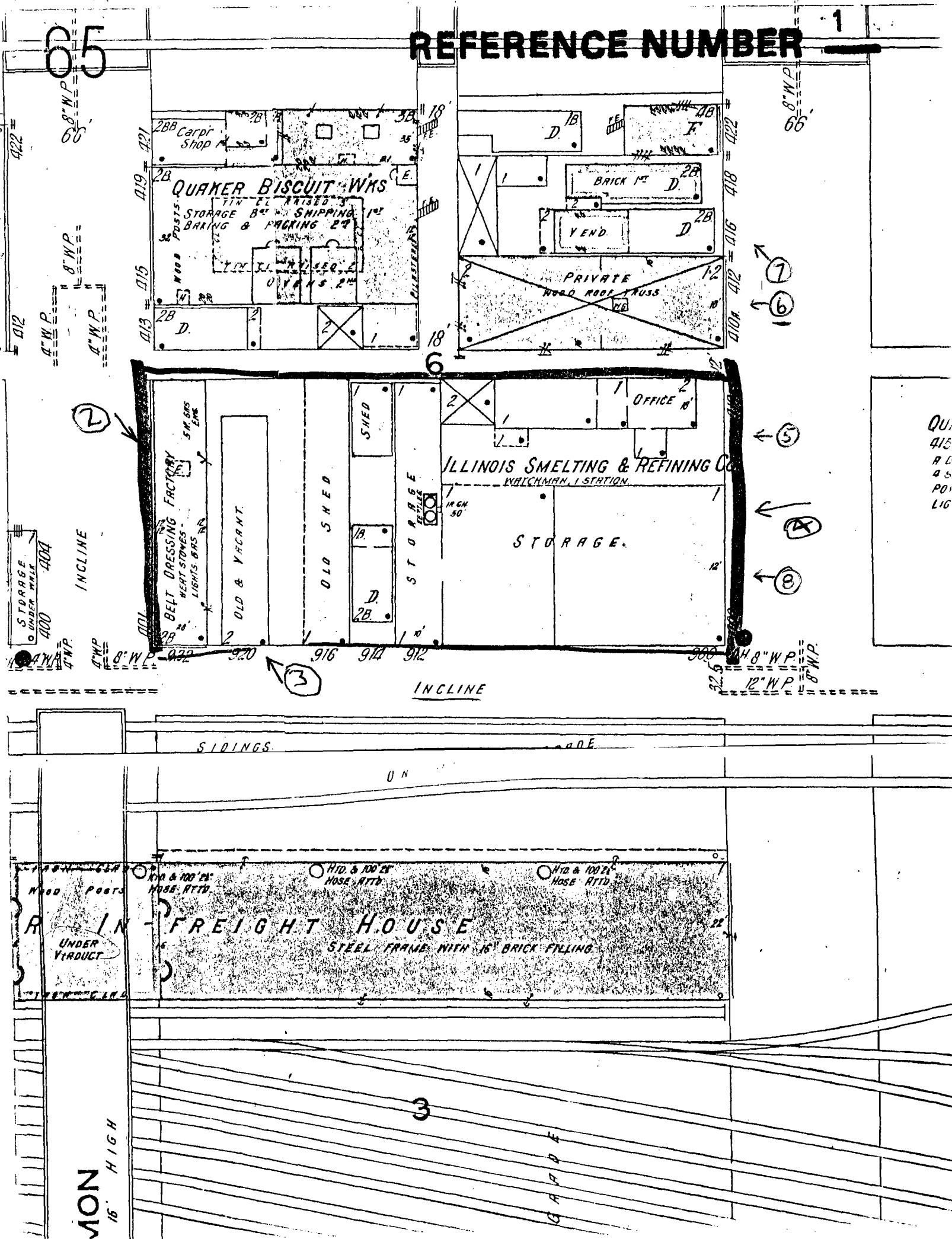
Reference Sheet

Reference 1 Sanborn Fire Insurance Map.

Reference 2 "Lead", Encylclopedia Americana.

Reference 3 "Lead", Encyclopedia Brittanica.

REFERENCE NUMBER



their production of leaden ornaments, statuary, and leader heads may still be found on such buildings as Windsor Castle, England, and the cathedrals of Amiens and Reims in France.

PROPERTIES

Lead is a soft, bluish gray metal that has a bright metallic luster when newly cut or melted. However, on exposure to air it takes on a silvery gray patina. In industrial atmospheres it changes to a dark gray or black. Lead can be scratched with a nail and is easily cut. Although lead can make marks on paper, graphite is used in pencils.

Lead is located in Group IVA of the periodic table. Its atomic number is 82, and its atomic weight is 207.19. There are isotopes of lead ranging from ^{194}Pb to ^{214}Pb . Natural lead consists of the isotopes ^{204}Pb , 1.5%; ^{206}Pb , 23.6%; ^{207}Pb , 22.6%; and ^{208}Pb , 52.3%. Lead has valences of 2 and 4. Its melting point is 327.4°C (621.3°F), and its boiling point is about 1750°C (3180°F).

Lead has a specific gravity of about 11.35 and is the densest of the common metals, except for gold. It is extremely malleable and ductile. Compared with copper, lead is a poor conductor of heat and electricity. However, lead is an excellent barrier to sound, and it is also a good radiation barrier.

Lead's very good corrosion resistance is due to its ability to form a thin protective coating on itself. Corrosion resistance is good when the coating is an insoluble lead salt, such as the sulfate, carbonate, or phosphate. If such coatings are broken mechanically, they tend to re-form on exposure to the environment. On the other hand, if a soluble coating is formed, such as the nitrate, acetate, or chloride, it offers little corrosion protection.

USES OF LEAD AND LEAD ALLOYS

Lead and its alloys can be shaped by almost all commercial processes. They can be extruded in such forms as pipe, rod, wire, ribbon, traps, bands, wedge lead, and special shapes. They are also rolled to produce such items as sheet, mill strip, and blanks for drawing, stamping, and spinning. These metals can be sand-cast or die-cast and made into metallic powder, wool, and

Storage Batteries. The storage battery industry uses large quantities of both metallic lead and lead oxides. Perforated grids are cast from alloy lead containing between 4% and 12% antimony, about 0.25% tin, and small amounts of arsenic, bismuth, and copper. On these grids the active material—lead oxides, is applied. See also BATTERY.

ELECTRIC—Lead Acid Batteries.

Solder. Solder, one of the most important industrial joining mediums, is an alloy of lead and varying percentage of tin, depending on the intended use. The most commonly used solder contains 50% tin and 50% lead. Major quantities of solder are used in the automobile industry—the soldering of radiators—the canning industry, the electronics industry, and the plumbing and sheet-metal trades. See also SOLDER.

Bearing Metal. Bearing metals containing 10% lead alloyed with tin, antimony, and copper are used in almost all kinds of bearings. These are automotive connecting rod, and camshaft bearings; diesel engine bearings; and railroad-car journal bearings.

Printing Metal. Type metal used in the printing industry varies in its components. However, it

is generally a combination of lead, tin, and antimony. For example, the metal used in linotype machines is an alloy of 84.5% lead, 4% tin, and 11.5% antimony.

Cable Coverings. Lead is used in the construction of two general types of electric cables—for communication over telephone and telegraph lines and for the transmission and distribution of electric power. The continuous lead sheath is applied over the conductor wires in large extrusion presses. An alloy of lead with 0.1% to 0.2% arsenic, 0.07% to 0.2% bismuth, and 0.05% to 0.25% tin is also used. This alloy has the advantages of increased tensile and bursting strength and higher annealing temperature.

Ammunition. Lead shot is manufactured in shot towers as high as 125 ft (37.5 meters). The molten lead falls through a sieve at the top of the tower and solidifies during its fall. It lands in a pool of water at the bottom. Up to 1% arsenic is added to the lead to increase its fluidity and to allow it to assume more easily the perfect spherical shape desired. For long-range loads, from 2% to 6% antimony is also added to shot to increase hardness. For bullets, lead is extruded as a wire, cut to length, swaged to the approximate shape, and inserted in the jacket. Lead is used in ammunition primarily because of its density.

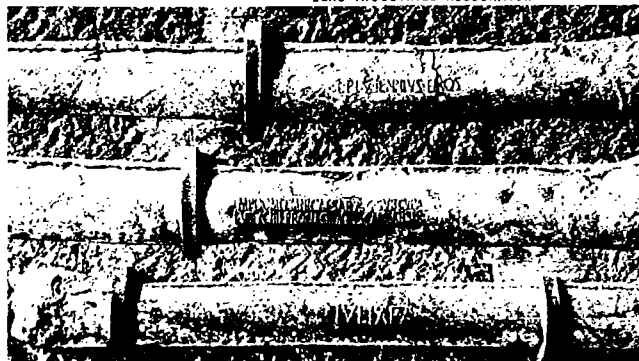
Sheet Lead. Sheet lead—made from soft lead or hard antimony-containing lead on large rolling mills—is used widely in the chemical processing industries, particularly where sulfuric acid is present. One of the basic processes in sulfuric acid production involves the use of a lead chamber. (See SULFURIC ACID.) It is also of basic importance in the plumbing industry. Foil, also produced on rolling mills, is used for X-ray film packaging and in the manufacture of paper-wound condensers and mica condensers for use in various types of electronic circuits.

Pewter. Early pewter was an alloy of tin and lead, with the lead content ranging from 1% to about 50%. However, the average was about 25% lead. The use of the high-lead pewter for tableware was very dangerous because of the chance of lead dissolving into the food. Modern pewter is a tin-antimony alloy and contains no lead.

Other Uses. Caulking lead is made from soft lead and is the jointing material for cast-iron pipe used for carrying water and sewage. Lead bricks are used as shielding to protect personnel working with X rays or with radioactive materials in atomic energy installations.

THESE LEAD PIPES were used by the Romans for conducting water more than 1,900 years ago.

LEAD INDUSTRIES ASSOCIATION



USES OF LEAD COMPOUNDS

A wide variety of lead compounds are used in industry.

Litharge. Litharge, or lead oxide (PbO), is a yellow, crystalline compound. It is one of the most widely used and commercially important metallic compounds. It is used, with small quantities of red lead, to form the active material on the plates of lead-acid storage batteries. Melted with other materials to form leaded glass, litharge is responsible for the ability of such glass to stop X rays and gamma rays. As a result, leaded glass is widely used for X-ray room windows and viewing ports around radioactive areas.

Litharge is used in all types of pottery and dinnerware glazes and in some porcelain enamels, particularly where the base metal is aluminum or copper. It is also used to produce chrome yellow and chrome green color pigments and serves as an accelerator, toughener, and controlling ingredient in the manufacture of rubber. It gives proper drying qualities to varnish, and as a catalyst it promotes more rapid polymerization of fatty acids in the oil used in varnishes. Dissolved in caustic soda, litharge is used in oil refining to break up some of the complex organic sulfur compounds in the petroleum products.

Tetraethyl Lead. Tetraethyl lead, $Pb(C_2H_5)_4$, is a heavy colorless liquid used almost exclusively as an antiknock additive in automotive and aviation gasolines. Because the lead in auto emissions can render some proposed emission control devices inoperable, there may be a decline in the use of tetraethyl lead in gasoline.

Other Oxides. Red lead, Pb_3O_4 , is a bright orange-red powder. Its two most important uses are in metal-protective paints and with litharge in storage batteries. It is also used in glass, glazes, and vitreous enamels.

Other lead oxides of commercial importance are the dioxide, PbO_2 , and orange mineral, Pb_5O_4 . Lead dioxide is a strong oxidizing agent utilized in the manufacture of dyes, matches, and rubber substitutes. Orange mineral has the same chemical composition as red lead but differs in color

and tone. It has a brilliant vermilion color and is used largely by color makers and manufacturers of printing inks. Black oxide, a mixture of litharge and finely divided metallic lead, is used mainly in storage batteries.

Silicates. Lead silicates, such as $PbSiO_3$, are used extensively as frits in the ceramics industry. There are several basic lead silicates of commercial importance. These serve as fluxes in the ceramics industry and as white pigments for exterior house paints and highway guardrails.

Other Compounds. A number of lead compounds are used as heat and light stabilizers in the production of vinyl plastics. These compounds include basic sulfates and phosphates, complex silicates, and organic compounds such as salicylates.

Other important lead compounds are the lead chromates, which serve as pigments. Chrome yellow, $PbCrO_4$, and chrome red, $PbO \cdot PbCrO_4$, are both used for their color. Chrome red is also utilized in rust-inhibitive paints. Blue lead, or basic lead sulfate blue, is used as a metal-protective paint. It is slate gray and consists of basic lead sulfate, small amounts of lead sulfite, lead sulfide, and zinc oxide plus a trace of carbon.

Lead azide, $Pb(N_3)_2$, is used as a primary detonating compound for high explosives. (See EXPLOSIVES.) Lead arsenate, $Pb_3(AsO_4)_2$, is a very poisonous compound used in insecticides and herbicides. Lead acetate, also known as sugar of lead, $Pb(C_2H_3O_2)_2 \cdot 3H_2O$, is a white crystalline compound used in the textile industry as a mordant in dyeing and printing cottons and for waterproofing. It is also used in the manufacture of varnishes and chrome pigments.

ORES AND METALLURGY

Lead is found in many countries throughout the world, with major concentrations in the United States, Mexico, Australia, Canada, and the USSR. Lead usually occurs with other metals, primarily silver and zinc. While many minerals contain lead, the one with greatest commercial importance is galena (lead sulfide, PbS). Of the other lead minerals, cerussite (lead carbonate,

IN FLOTATION CELLS
ponent of the ore is

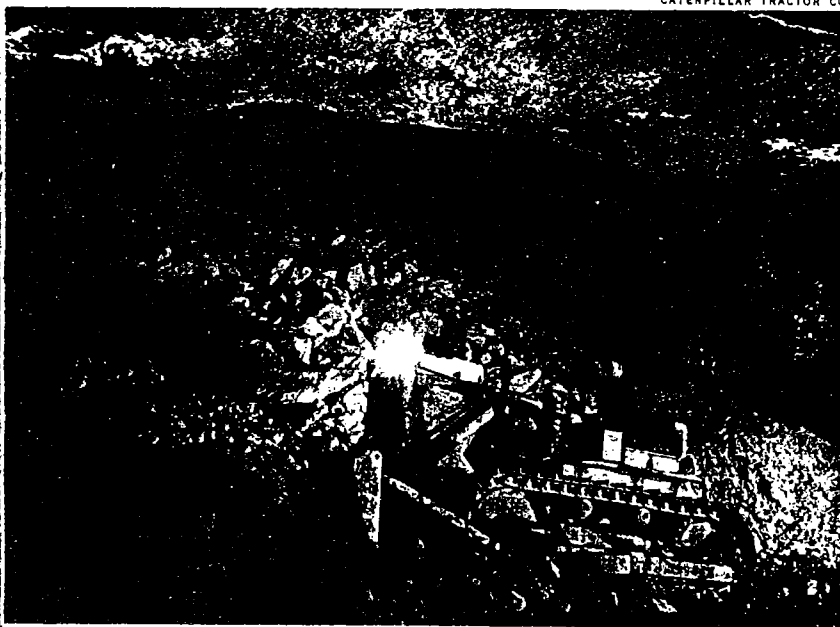
MOLTEN LEAD (right) is
of its low melting point,

$PbCO_3$) and anglesite
also of commercial im
are much less commo
In the recovery of
is first concentrated an
Much of the lead used
coverings, and various
used. This is possible
resistance and because
from contaminating m

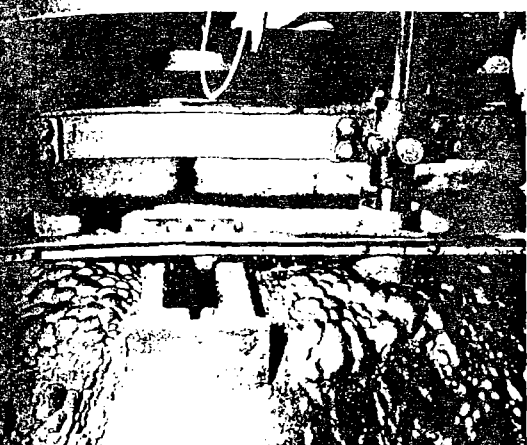
Concentration. Lead
tance contains from 2
However, the average
ore is recovered from
concentrating mills at
move as much of the
the sulfide ores the fl
used. In this process,
with about four times
amounts of other com
mass is then agitated
As a result of the ag
most of the metallic
formed on the top o
valueless gangue mate
the froth flows from
dried. The lead conc
the concentration mill
or more lead.

Smelting. Smelting
generally conducted in
Concentrates can be lo
must be roasted to re
and to agglomerate the
this agglomeration p
The sintered concentr
of lumps, is then lo
heated blast furnace
suitable fluxes. Coke
of air is admitted to th
to aid combustion and
of metallic oxides, w
by the coke and carb
nonmetallic waste form
The blast furnace
lead flows off into ket

CATERPILLAR TRACTOR CO.



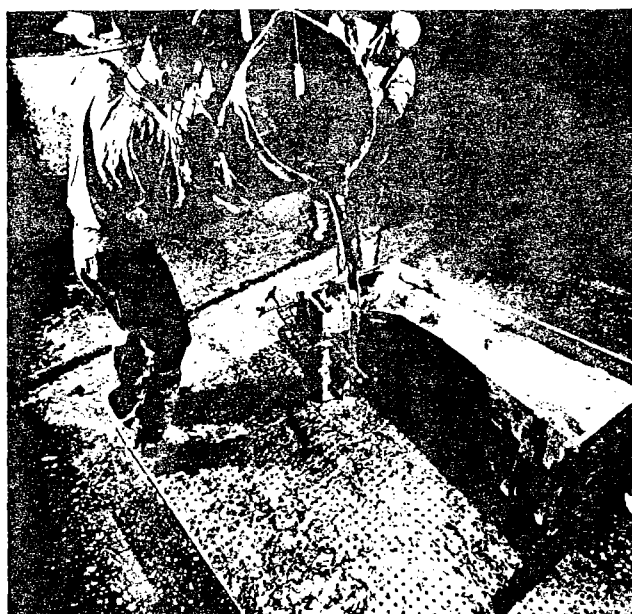
LEAD AND ZINC ORES are ex-
tracted from underground mines
by the use of heavy earth-moving
equipment at Galena, Ill.



LEAD INDUSTRIES ASSOCIATION

IN FLOTATION CELLS (above), the lead-rich component of the ore is skimmed off with the froth.

MOLTEN LEAD (right) is poured into a mold. Because of its low melting point, lead is easily cast.



LEAD INDUSTRIES ASSOCIATION

$PbCO_3$) and anglesite (lead sulfate, $PbSO_4$) are also of commercial importance. However, they are much less common than galena.

In the recovery of lead from its ores the metal is first concentrated and then smelted and refined. Much of the lead used in storage batteries, cable coverings, and various alloys is salvaged and re-used. This is possible because of lead's corrosion resistance and because it can be easily separated from contaminating material.

Concentration. Lead ore of commercial importance contains from 2% to more than 20% lead. However, the average is close to 4%. After the ore is recovered from the earth, it is treated at concentrating mills at or near the mines to remove as much of the waste rock as possible. For the sulfide ores the flotation process is generally used. In this process, finely crushed ore is diluted with about four times as much water and small amounts of other complex organic reagents. The mass is then agitated violently in a flotation cell. As a result of the agitation, a froth containing most of the metallic constituent of the ore is formed on the top of the mixture, while the valueless gangue material remains at the bottom. The froth flows from the flotation cell and is dried. The lead concentrates then shipped from the concentration mill to the smelter contain 60% or more lead.

Smelting. Smelting is a continuous operation generally conducted in blast furnaces. Before the concentrates can be loaded into the furnace, they must be roasted to remove most of their sulfur and to agglomerate the very fine flotation product. This agglomeration process is called *sintering*. The sintered concentrate, which is in the form of lumps, is then loaded into the top of the heated blast furnace with limestone and other suitable fluxes. Coke is used for fuel. A blast of air is admitted to the lower part of the furnace to aid combustion and to complete the formation of metallic oxides, which are reduced to metal by the coke and carbon monoxide present. The metallic waste forms a slag with the flux.

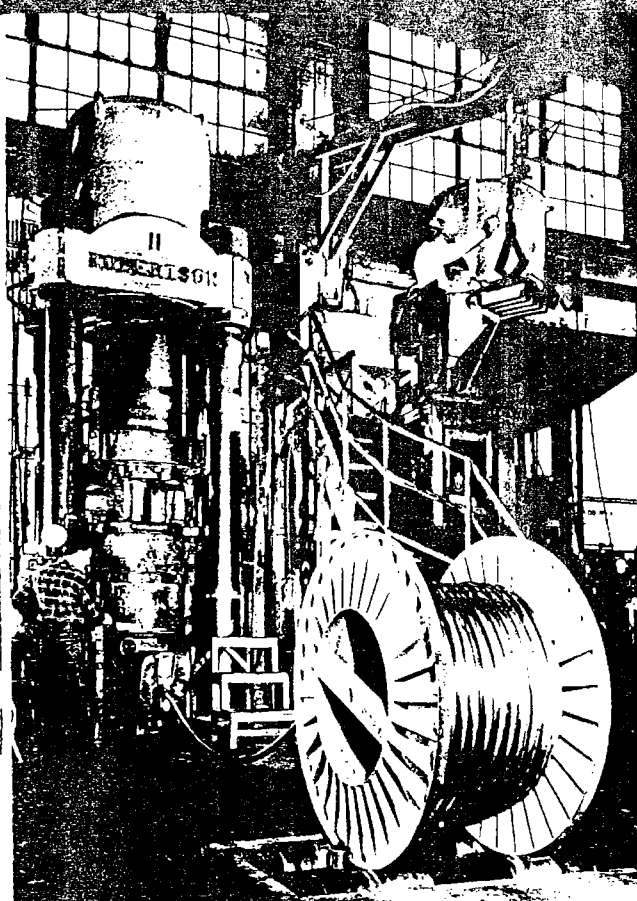
The blast furnace is then tapped so that the molten lead flows off into kettles or molds. In this form

the lead is a semifinished product known as *base bullion*, which may contain small amounts of gold, silver, copper, zinc, antimony, arsenic, bismuth, and other impurities. As the molten metal from the blast furnace cools, some of the impurities, particularly copper, separate and form a scum, or dross, on the surface. The dross is skimmed off and the copper recovered from it. Other impurities are then removed by refining processes in order to produce lead of commercial quality.

Refining. The most widely used refining method is the Parkes process. In this process the lead is first melted and allowed to cool below the freezing point of copper. Any copper present then crystallizes and is removed by skimming. The impure lead then passes to a reverberatory, or softening, furnace, where the temperature is raised and the molten lead is stirred. Traces of antimony and arsenic, which are impurities that harden lead, are oxidized by a blast of air, and the oxides are skimmed off.

After softening, the lead goes to desilverizing kettles, where small quantities of zinc are added. Both gold and silver are more soluble in zinc than in lead, so that if these metals are present in the lead they become dissolved in the zinc when it is added. Since zinc is lighter than lead, the zinc rises to the surface. When the temperature is lowered, the zinc solidifies and is skimmed off. Afterward the little remaining zinc is oxidized and skimmed off in a reverberatory furnace. Zinc may also be removed by creating a vacuum over the surface of the molten lead. The zinc vaporizes, and the vapor is condensed as metal on the cool dome of the vacuum vessel, where it is collected.

The Betts process for refining lead is an electrolytic method particularly useful for purifying bullion containing high concentrations of bismuth. In this process the bismuth is recovered from the lead and is a valuable by-product. Bismuth is not removed during refining by the Parkes process. In the Harris process, molten caustic salts are used to remove the impurities from desilverized lead.



LEAD INDUSTRIES ASSOCIATION

LEAD-SHEATHED CABLE produced by a sheathing press is automatically rolled onto a large cable reel.

Some lead ores, such as those from southeastern Missouri, contain such low concentrations of silver that it is uneconomical to try to remove it. Therefore, the finished pigs from such ores, while free from other impurities, are noted for their comparatively high silver content.

WORLD PRODUCTION

World production of smelter lead totals approximately 3.8 million short tons (3.45 million metric tons) annually. The leading lead-mining countries are the United States, the USSR, Australia, Canada, Japan, France, Mexico, Bulgaria, Communist China, Yugoslavia, and West Germany. The first three are by far the largest producers. In the United States, most of the lead is obtained from mines in Missouri. The next largest producers are Idaho, Colorado, and Utah. The United States, the world's largest producer, is also the largest consumer of lead.

DAVID BORCINA, *Lead Industries Association*

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LEAD-CHAMBER PROCESS. See SULFURIC ACID—Chamber Process.

LEAD POISONING is a form of poisoning caused by the absorption of lead from the digestive tract, from the lungs, or through the skin. Most cases of lead poisoning in the United States occur among children who eat chips of lead-containing paint that have peeled off the ceilings and walls of deteriorated housing. Lead paints were widely used for home interiors until the 1940's, and in many city slums, where buildings have been poorly kept, 15% to 20% of the children between the ages of one and five show evidence of lead ingestion. It is estimated that 3% to 5% have potentially toxic levels of lead in their blood. In many large cities hundreds of cases among children are reported each year, but it is believed that the actual number may be much higher.

In industries that use lead or lead compounds, lead poisoning among workers is a potentially serious hazard, but present control measures are so stringent that cases of industrial poisoning are rare. Tetraethyl lead, a compound added to gasoline as an antiknock agent, is an important source of airborne lead because some of it is discharged through the exhaust. Present levels of lead in the air are not considered high enough to cause poisoning, but surveillance is indicated.

Lead in the Body. Typically, an adult ingests about 0.3 milligrams of lead daily. Of this, only about 10% is absorbed from the intestine. Similarly, only a fraction of inhaled lead enters the blood. Most lead excretion is through the kidneys. Lesser amounts are excreted in the feces and sweat. If lead ingestion exceeds 0.6 milligrams daily, the body's ability to excrete it diminishes, and as lead accumulates in the body, poisoning develops. Most cases among children occur in the summer, perhaps because of the enhanced intestinal absorption of lead from the action of vitamin D. Exposure to sunlight increases the body's production of this vitamin.

Lead has no known beneficial effects in the body, but it may cause great harm. It is known to interfere with normal hemoglobin production and may also affect the kidneys and heart. The most important damage occurs within the central nervous system (brain and spinal cord), where lead has a direct toxic effect on brain metabolism. Swelling of the brain may follow. In adults, damage to the peripheral nerves has been noted.

Symptoms. Symptoms of lead poisoning develop slowly after several months of lead ingestion. Early symptoms are mild diarrhea, anemia, and irritability. As the level of lead rises, stupor and convulsions occur, often leading to death. A significant proportion of persons who recover have residual brain damage.

Treatment and Prevention. Lead poisoning is treated by administering a chemical agent that binds the lead in a nontoxic form that can be safely excreted in the urine. Such treatment, however, may be hazardous and take several months. The prevention of lead poisoning, therefore, is of prime importance. An effective prevention program includes making the public aware of the danger, testing paint in dilapidated houses, examining children for evidence of lead ingestion, and keeping afflicted children out of unsafe houses.

EVAN CHARNEY, M. D., *University of Rochester School of Medicine and Dentistry*

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LEADBELLY, led'bel-ē, American folk singer with his unrivaled mastery. He was one of the first of the Deep South to win an international reputation. Born Huddie Ledbetter, he was taken to Texas, learned to play the guitar, was taught to sing the early blues by Blind Lemonnier. He traveled as a helper in charge in 1918, Leadbelly from 1930 to 1934 in the State Penitentiary of Texas. There he was discovered by Lomax, who got him out of the penitentiary and again for assault in 1934. He returned to Lomax. Leadbelly on a highly successful tour of the United States, Paris, where he appeared in 1938. He died in New York City in 1942.

The violent episode helped make him a living blues singer. One party counted: he was not, done by the governor of his singing. His disfigurement remains, undisputedly.

GILBERT CHASE,

LEADVILLE, led'vil, a town in the seat of Lake county, Colorado, at an altitude of about 10,200 feet in the Rocky Mountains, 120 miles from Denver. For over a century a mining center. Tourist attraction. A camp called Orem was the site when gold was discovered. The gold vein dwindled, but the rich lead and silver deposits boomed. When Leadville was founded in 1878, its population of 10,000 was the second-largest city in Colorado. The population was estimated at 10,000 in 1880.

Mining magnates in the Leadville mines were Horace A. W. Tabor and his wife. Tabor was a rich strike. The mine was one of the most productive from the boom of the 1880s. Matchless Mine where Tabor's second wife, Kate, was a landmark.

When the price of silver declined, but in 1890 reopened and the world's largest producer of silver. The world's largest producer of silver.

LEADWORT, led'wōrt (Plumbaginaceae) of which are many of which are given by flower clusters. Leadworts are the three genera (*Limonium*, *Plumbago*, and *Ceratophyllum*). Only called leadwort and 400 species.

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simplicity and archaic affectation and using to advantage the know-how gained in primitive desert conditions and acquired as aircraft mechanic and boat handler to enrich the language with unhackneyed accuracy.

No additional book by Lawrence was published in his lifetime other than a minor translation he had done under his J.H. Ross pseudonym, *Adrien le Corbeau's Forest Giant* (1924), although his wartime *Arab Bulletin* dispatches to Cairo (adapted into *Seven Pillars*) appeared as *Secret Despatches from Arabia* and a miscellany as *Oriental Assembly* (edited by A.W. Lawrence), both posthumously in 1939. His first postwar writings, including a famous essay on guerrilla war and a magazine serial version of an early draft of *Seven Pillars*, have been published as *Evolution of a Revolt* (edited by S. and R. Weintraub, 1968). *Minorities* (1971) reproduced an anthology of more than 100 poems Lawrence had collected in a notebook over many years, each possessing a crucial and revealing association with something in his life.

Last years. Lawrence's last years were spent among RAF seaplanes and seagoing tenders, although officialdom refused him permission to fly. In the process, moving from bases on the English Channel to those on the North Sea and leading charismatically from the lowest ranks as Aircraftman Shaw, he worked on improved designs for high-speed seaplane-tender watercraft, testing them in rigorous trials and developing a technical manual (*The 200 Class Royal Air Force Seaplane Tender*, 1932) for their use. A stencilled and duplicated production, it was as unpretentious as his first book had been opulent.

Discharged from the Royal Air Force on February 26, 1935, Lawrence returned to Clouds Hill to face a retirement, at 46, filled alternately with optimism about future publishing projects and a sense of emptiness. To Lady Astor, an old friend, he described himself as puttering about as if "there is something broken in the works . . . my will, I think." A motorcycle accident on May 13 solved the problem of his future. He died six days later without regaining consciousness.

Lawrence found despair as necessary as ambition. He lived on the masochistic side of asceticism, and the non-physical part of his self-punishment involved creating within himself a sense of deep frustration to immediately follow, and cancel out, high achievement by denying to himself the recognition he had earned. At its most extreme it involved a symbolic killing of the self, a taking up of a new life and a new name. Under whatever guise, he was a many-sided genius who by his achievements denied himself the privacy he constantly sought and by the manufacture of his myth, however solidly based, created in his own person a characterization rivalling any in contemporary fiction.

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(S.We.)

Lead Products and Production

Lead, a heavy, malleable, durable metal with a low melting point, has found a wide range of applications throughout history and in terms of world tonnage today remains one of the most important metals produced.

History. The Egyptians may have used lead as early as 5000 BC. Applications in the ancient world included use as weight standards, in coinage, for ornamental objects, for refining silver, as solder, and as a glaze for pottery. The Egyptians used red lead, an oxide of lead, as a cosmetic pigment. A lead figure dating from 3800 BC was found at the temple of Osiris, on the site of ancient Abydos, and is now in the British Museum. About 2000 BC the Phoenicians were mining lead deposits in Spain, and it was at about the same period that the Chinese first employed lead in their monetary system. Later, when silver coins replaced lead, the mining of lead was prohibited to prevent counterfeiting, but lead became and remained the principal metal used to debase silver for counterfeiting purposes into modern times.

Lead was well known in biblical times and is used metaphorically in Exodus in noting that the pharaoh's host "sank as lead" in the Red Sea. The Hanging Gardens of Babylon, built about 600 BC, are said to have had floors sheathed with sheets of lead soldered together to hold the soil and moisture.

The lead mines at Laurium, Greece, flourished in the 5th century BC and in the 3rd century BC the Romans operated mines in the Río Tinto region of Spain. The Romans used lead pipe extensively, and fabricated it in 15 standard-sized diameters, all ten feet (3 metres) long. Many sections of pipe in almost perfect condition have been unearthed at Pompeii, Rome, and Roman sites in England. Indeed, the Latin word for lead was *plumbum*, denoting water conductors or spouts; from it is derived the word plumber. The Romans also made wide use of lead in soldering.

Lead applications multiplied in the Middle Ages; lead "comes" held the fragments of stained-glass windows together, and lead gutters, drainpipes, and interior pipes were fashioned for churches, monasteries, castles, and houses.

Almost since the beginning of warfare, lead has been important in missiles because of its low melting point

Lead in
Roman
times

(which made it easy to fabricate) and its high density. Lead chunks were hurled with slings, and molten lead was poured on attackers from fortress walls. Lead bullets and shot have been used since the inception of firearms.

The medieval alchemist, who preceded today's chemist and metallurgist, considered lead the father of all metals, and its low melting point was a factor that led him to try to convert it to a substance that would transform other base metals into gold.

In the United States, now the world's major lead-producing country, lead mining and smelting began in Virginia in 1621. Lead ores from the Mississippi Valley were used from 1700 to 1867, when the first of the great western mines was opened.

Lead ores: galena. Galena (lead sulfide), by far the most important primary lead ore mineral, frequently contains as impurities zinc, copper, cadmium, bismuth, arsenic, antimony, and silver; often the silver value is greater than that of the lead, in which case it is a true silver ore. A primary mineral is formed by natural processes and unaffected by subsequent events, while a secondary mineral is affected in some way; for example, by weathering. Other primary lead minerals are clausthalite, altaite, jordanite, kobellite, boulangerite, aikinite, jamesonite, and bournonite. Carbonates and sulfates, formed by weathering, are the chief secondary minerals. The most common, cerussite (lead carbonate), is formed by the action of carbonate groundwaters on galena. Anglesite (lead sulfate) is derived from galena that has been contacted by sulfate solutions generated from the oxidation of sulfide minerals. Other oxide minerals of lesser importance are wulfenite, vanadinite, and pyromorphite. Lead is rarely found in its elemental form.

Over 95 percent of mined lead is from primary ores in which galena is the preponderant lead mineral. Galena is usually intermixed with other sulfides, chiefly sphalerite (zinc sulfide) and the sulfides of iron: pyrite and marcasite, less commonly with chalcopryite (copper and iron sulfides). Lead ores constitute the chief source of silver, usually in solid solution with galena.

PRODUCTION PROCESSES

Mining. The widely varying characteristics of lead ores have given rise to many mining techniques, of which underground methods predominate. Most lead deposits occur at moderate depths in narrow channels called veins or in deposits of roughly spherical shape (lodes). Both veins and lodes are of varying thicknesses. Holes are drilled for blasting, often by large mounted diamond drills or carbide percussion drills. After blasting, the broken ore is sorted and loaded onto cars or continuous belts for transportation to the surface. Most modern lead mines are highly mechanized.

Ore treatment. Although galena contains 86.6 percent lead, it usually occurs dispersed with other minerals, and in some places, ores with as little as 3 percent to 30 percent lead are mined.

Preparation for roasting. Lead ore is prepared for roasting by grinding, flotation, and concentration. First, the ore is ground and classified by particle size: approximately 70 percent is less than 0.0017 inch in diameter, and 90 percent less than 0.0029 inch; some particles are less than 0.0003 inch. The ground and classified ore, which is a mixture of lead sulfide and worthless rock called gangue, passes to large tanks where flotation takes place.

Flotation separation process

Flotation, which has supplanted earlier methods of mechanical and gravity separation, takes advantage of the fact that water with a suitable wetting agent added to it, wets gangue but not lead sulfide. In the flotation tank, the ground and classified ore is mixed with water and some flotation agent such as oil. The lead sulfide attaches itself to the oil, which is turned into froth by bubbling air into the mixture, and then is floated off the top. The wet gangue sinks to the bottom of the tank and is discharged.

Concentration involves aggregating the tiny particles of lead sulfide; this is done with the aid of an agent such as lime or alum. Filtered to reduce its water content to about 10 percent, the concentrate then passes to the smelter. Concentrates include 45 to 60 percent lead,

along with varying amounts of impurities: 10 to 30 percent sulfur, up to 15 percent zinc, 8 percent iron, 3 percent calcium oxide, 3 percent copper, 2 percent antimony, and small amounts of arsenic, bismuth, gold, silver, and other elements.

Roasting. Before lead concentrates can be added to the furnaces, they must be treated to lower the sulfur content because the ordinary furnace does not reach a high enough temperature to reduce lead sulfide. Substances such as limestone, iron ore, silica, coke, etc., are mixed with ore concentrate; these fuse with the sulfur in the lead sulfide to form compounds. The ore mix is laid on a moving grate; air is blown through the mass; sulfur acts as the main fuel, forming sulfur dioxide, which is usually recovered for sulfuric acid manufacture. The mix is fused into a strong, homogeneous material called sinter, comprised primarily of oxides of lead, iron, and zinc, with substantial amounts of metallic lead and a little sulfur. The porous sinter mass is broken into lumps as it is discharged from the moving grate. Sinter clinkers up to five inches (125 millimetres) in size are passed over grates to remove the fine particles, which are stored for blending with other materials prior to reduction in the blast furnace. Reduction is the removal of oxygen from a compound; for example, reduction of lead oxide yields metallic lead.

Smelting. Smelting is the continuous reduction of ore constituents to metal, generally carried out in a blast furnace, which consists mainly of a water-jacketed shaft or column up to 24 feet (7.2 metres) high with a rectangular cross section and is loaded from the top. The lead or charge consists of properly proportioned sinter, limestone, coke, silica, and other fluxes. Orifices called tuyeres, through which air is blasted, are positioned just above a crucible at the bottom of the shaft. The crucible collects molten lead and is arranged with a suitable siphon well so that the molten lead can be removed from the furnace without affecting the blast pressure within the furnace. Ports to discharge slag and metallic waste (matte) are located near the top of the crucible. Sight glasses that allow for visual inspection of the smelting reaction are located in the tuyeres. Air is injected to aid combustion and to complete the formation of metallic oxides, which are then chemically reduced to metal by the coke and carbon monoxide present. Nonmetallic waste forms a slag with the fluxing materials. A balanced smelting charge of iron, limestone, and silica yields a slag that is fluid. When the coke and sinter ratio is not correct, there is an improper reduction of ore to metal.

Reverberatory furnace smelting, in which a furnace charge is held in a basin-like vessel and heated by flames on the surface to effect the reduction, is rarely practiced in lead refining as it requires that the ore contain 70 percent or more lead.

The output of the blast furnace is lead bullion, which contains dissolved metallic and nonmetallic (oxide and sulfide) impurities. Slag, matte, and other products of the blast furnace are either further treated to recover metal values or scrapped.

Drossing. Lead bullion is maintained in a molten state just above its melting point in a drossing kettle, which contains up to a hundred tons. (The term dross refers to any solid scum floating on top of a metal bath comprised of metal oxides, sulfides, metallic compounds, etc.) At temperatures of about 330° C, remaining impurities are brought to the surface by stirring, by the addition of small amounts of sulfur, and by agitation with submerged air lances and are removed by skimming.

Refining. The bullion is transferred to the refinery either as a pumped liquid or as large cast blocks, weighing as much as ten tons.

Electrolytic refining. Electrolytic refining involves purifying the bullion by means of electricity. If electrolytic refining is to be practiced, the bullion is cast into anodes (or plates) weighing several hundred pounds. These are hung in electrolytic tanks where they dissolve; pure lead is deposited on a thin sheet of lead that serves as the cathode. Impurities left behind can be recovered by many complex operations.

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Kettle refining. Kettle refining of bullion is complex, but the recovery of by-product silver and gold is simpler and faster. All of a number of kettle-refining processes or modifications have the following steps: softening, desilverizing, dezincing, and debismuthizing. Softening refers to removal of impurities that harden lead, such as antimony, arsenic, tin, zinc, and others. Large-capacity steel pots or reverberatory furnaces are used to hold the bullion at red heat. Blowing with air or applying suitable oxidizing reagents oxidizes impurities. The oxidation is selective and oxide drosses or slags in which each element is concentrated can be removed by skimming.

Silver is removed from softened lead by adding zinc and raising the temperature sufficiently to melt it (about 540° C). With stirring, the molten zinc reacts, forming compounds with gold and silver, plus traces of copper and nickel. These zinc compounds are lighter than the metallic lead; on cooling, they form a crust that is removed. The gold and silver are recovered in a parting plant. The lead is now treated for removal of the remaining zinc by a vacuum process. The zinc recovered from the vacuum retort, along with that from the parting plant, is reused.

If the bismuth content is too high, the softened lead is next debismuthized. The operation is similar to desilverizing, except that a combination of calcium and magnesium metals are used as the reagents to form high-melting-point intermetallic compounds with bismuth, which are skimmed off and treated for recovery of bismuth.

The refining processes yield pig lead of good marketable uniformity and purity. Large quantities of pig lead are available, 99.999 percent pure.

MAJOR USES

Lead is widely used both in the metallic form and in chemical compounds.

Storage batteries. The lead-acid storage battery, the largest single use for lead, remained in the early 1970s the most dependable apparatus by which electrical energy can be conveniently stored for future use. Economy, reliability, and the ability to deliver large amounts of energy in a short time have made it an essential part of every automobile. Storage-battery grids require a metal with a low melting point, high corrosion resistance, and certain electrical properties. The modern automotive SLI (starting, lighting, ignition) battery consists of about one-third lead metal (grids, posts, and connectors) and two-thirds litharge (lead monoxide). The lead metal, 6 to 12 percent antimonial lead plus a small amount of tin, is almost wholly recovered by smelting secondary materials, mostly scrap storage batteries. Litharge mixed with sulfuric acid to a paste consistency for incorporation into the metal grid is usually made from primary (mined) lead because impurities such as silver and bismuth cannot be removed economically during refining of secondary (salvaged) lead.

Storage batteries are also used as a standby source of power for telephone exchanges, power companies, hospitals, submarines, etc. The thicker grids used for this type of service do not require the casting properties of the SLI batteries. In order to minimize the self-discharge caused by antimony-containing grids, pure lead or calcium-lead alloy is used. The calcium content of 0.06 to 0.08 percent in lead yields an alloy of essentially the same physical properties (primarily improved mechanical strength) as 4 percent antimonial lead, necessary characteristics in battery production and use. Large industrial batteries supplying energy for electric locomotives, industrial trucks, and some experimental electric automobiles usually have antimonial lead grids.

Chemical lead. Lead is used extensively in the construction of chemical-plant equipment. If unalloyed lead is used it is generally of the grade commonly known as chemical lead, sometimes termed acid lead, or copper lead. The term chemical lead denotes a metal of very high purity: standards vary slightly from country to country. Chemical lead forms a tightly adherent, insoluble lead sulfate film in sulfuric acid solutions. As sheet, pipe, rod, etc., it is readily welded (burned) into complex structures for holding and conveying sulfuric acid mixtures. Other

materials, such as plastics, rubber, etc., have been used for similar operations, but lead's demonstrated corrosion resistance over a wide range of conditions, its ease of repair, and, after a long useful life, its high salvage value have enabled it to retain its position as a material of construction in the chemical industry. A 6 percent antimony-chemical lead alloy is used where greater strength or fatigue resistance is required. The use of 6 percent alloy is restricted to temperatures below 125° C because of its lower melting point. Similar alloys are used with phosphoric acid, hydrofluoric acid, chromic acid, and other corrosive environments where insoluble protective films are formed. Each different smelter uses a proprietary alloy as insoluble anode in chromium plating, and electrowinning (recovery by electrolysis) of copper. To achieve a higher order of strength, lead-lined and lead-covered steel pipe, fittings, valves, and vessels are used with lead metallurgically bonded to the substrate to maintain suitable heat transfer.

Other uses. The electric cable in industry is a major user of lead. Lead alloys, usually 1 percent antimonial lead, can be easily extruded, forming an impervious corrosion-resistant cover on telephone and power cables. When the cable is replaced, the sheathing can be recovered by a simple stripping operation, refined, and used to cover new cable.

Lead has a longer record of satisfactory performance than any other water-service pipe material. The flexibility of lead pipe allows adjustment to ground settlement without damage, and minimizes the number of joints. Lead is also used for caulking joints in cast-iron water mains and sewer and soil pipes. Because it withstands the effects of polluted air and water, lead is useful in drainage and venting systems.

Sheet-lead roofing and flashing have long been used on buildings because of their durability under all types of climatic conditions. The development of special alloys capable of resisting buckling due to alternating high and low temperatures (thermal cycling) has caused a renewed interest in the use of lead in modern architecture. Special joint designs have also helped in the construction of essentially maintenance-free roofs, reflecting pool liners, etc., and soft lead comes are easily worked to form leaded art-glass windows.

Ammunition, both military and sporting, accounts for a large use of lead. Spherical shot for shotgun use is made by pouring molten 2 to 6 percent antimonial lead, with up to 1 percent arsenic added, through suitable sieves at the top of a 125-foot tower. The molten alloy, while dropping, forms a true sphere before solidifying near the bottom of its fall. The shot is collected in water, removed, dried, and sorted for size and sphericity. Military ammunition is formed into bullets by swaging (cold-shaping) extruded wire in suitable dies.

The densest of the common metals, lead is widely used for radiation shielding. It prevents the penetration of gamma rays and neutrons, and since it does not itself become radioactive, it may be used continuously. High density glasses, containing as much as 80 percent lead oxide, are used as windows in radiation installations.

Due to its limpness and high density, lead is finding expanding use in the control of noise pollution. Thin-cast sheet lead is used for encasing noisy machinery, or in room partitions for keeping noise out. Jet airliners use a lining of an adhesive-backed layer of vinyl plastic compounded with lead powder to keep the noise level in the passenger compartment to a minimum.

LEAD ALLOYS AND COMPOUNDS

Lead alloys. The mechanical properties of pure lead are quite poor; therefore, when more strength is required, lead is alloyed with other elements.

Antimony. The most common metal used is antimony, which on additions up to 12 percent by weight not only increases the tensile strength of the alloy as much as four times but also lowers the melting point. As noted earlier, antimonial lead is used as a storage-battery grid metal.

Tin. Tin alloyed with lead in amounts from 2 to 70 percent by weight forms the solders widely used in indus-

Architectural applications

Industrial
soldering
alloys

try. Not only is the strength of the alloy increased with higher tin content but the melting point decreases from 327° C for lead to 183° C for 63 percent tin-37 percent lead. Solders of 2 percent tin-lead are used for automatic soldering of tin-coated steel cans. Industrial solders, used for such applications as automotive radiators, contain from 5 to 30 percent tin. The electronic solders are generally of the lowest melting point (63 percent tin), so that the temperature-sensitive components will not be damaged.

Casting alloys. Lead alloys containing antimony and tin form a series of low melting metals with excellent casting properties and the ability to produce intricate castings with excellent detail. Linotype metal with 4 percent tin and 12 percent antimony, used for casting the finest printer's type, exhibits suitable strength for use on a press. Electrotypes and stereotype metals used by printers also have excellent casting properties. Ornamental castings, which are usually plated with silver or other metals, are made with 11 percent antimonial lead, with about 0.5 percent arsenic added to increase the strength and to yield better detail and a smooth-surface finish. Lead alloyed with varying combinations and amounts of bismuth, tin, cadmium, antimony, indium, or gallium yields a series of metals that have very low melting points, culminating in one so low that it can be melted in the palm of the hand. Such alloys, rated as to melting point, are widely used for equipment of very high reliability.

Bearing metals. Lead-base bearing metals are usually antimonial lead with additions of tin or copper or both and arsenic to increase the compressive strength. The ability of these alloys to maintain a thin film of lubricating oil at relatively high loads and speeds prevents wear on the bearing-metal surface. The alloys are sufficiently soft so that even in case of lubrication failure no damage is done to the rotating shaft. The use of thin layers of bearing metal, with a stronger backing material reinforcing the lead alloy, increases the load-carrying capacity of such bearings.

Lead compounds. At least a third of all lead produced is used in chemical compounds. Most of the uses of lead discussed thus far are not consuming uses, in that the metal eventually returns as scrap for secondary refining and reuse. The chemical compounds, which generally use corroding lead (lead refined to a high degree of purity) as a base, are generally dissipated into the atmosphere or elsewhere so that recovery is impossible.

Gasoline additives. A major use of lead compounds in the 1960s was in gasoline additives, such as tetraethyl lead to form the antiknock, high-octane gasoline required by high-compression internal combustion engines. This use was declining in the 1970s owing to air-pollution problems.

Paint pigments. The earliest known and one of the most widely used lead paint pigments is white lead (basic lead carbonate). A process for making white lead starts with metallic lead blown with steam or air to produce a fine powder, which is then treated with acetic acid, air, water, and carbon dioxide gas in long, revolving wooden cylinders. The process requires about 12 to 14 days for conversion. Recent modifications of the process use litharge as the starting reagent to shorten the production time. The outstanding characteristic of white lead is its chemical affinity for paint vehicles, becoming an integral part of the paint film. This reinforcement results in a tough, flexible film, unusually resistant to embrittlement.

Basic lead sulfate, also called basic sulfate white lead, is a pigment used in mixed paints with the same properties as basic carbonate white lead.

Red lead (Pb_3O_4) is manufactured in furnaces by heating litharge at a carefully controlled low temperature. Litharge takes up more oxygen to form red lead. A part of the litharge usually remains unconverted in the core of red lead particles. A 98 percent true red lead is used for paint.

Litharge. Litharge (lead monoxide) is one of the most important and widely used metallic compounds. It is produced by melting pig lead in the presence of air, or occasionally by burning lead to a fume in the presence of

oxygen. It is possible to produce a specific type of litharge for almost any use, and the various commercial grades are generally known by the uses to which they are put. Storage batteries account for the largest consumption of litharge. Battery litharge is very pure and may be blended with some red lead and other additives to form the active material of the plates. Glassmaker's litharge is a high-purity flake or powder, which must be free of iron or other impurities that would discolour the glass. Similarly, pottery maker's and enameller's litharge must be pure. Porcelain-enamelled aluminum sheets have litharge as a major constituent in the coating. Colourmaker's litharge is reacted with acetic acid to form lead acetate. Various compounds added to the lead acetate precipitate a number of pigments, such as chrome yellow, chrome red, and chrome green.

Other compounds. Lead arsenate, an insecticide, can be prepared by dissolving litharge in arsenic acid, with acetic or nitric acid as the catalyst, or litharge may be converted to lead acetate or nitrate and allowed to react with sodium arsenate.

Lead azide is an initial detonating agent for high explosives, such as TNT. Crystalline lead azide is prepared by the slow addition of a dilute solution of sodium azide to a constantly stirred dilute solution of lead acetate or nitrate. The precipitated azide is washed with water and stored under water or a 50-50 mixture of water and ethyl or methyl alcohol. By varying procedures it can be prepared as a colloid or treated with starchy compounds called dextrans to achieve certain properties.

Lead dioxide (PbO_2) is formed electrolytically by anodic oxidation of metallic lead. In neutral or alkaline solutions the alpha crystalline form of lead dioxide is formed. In acid solutions the beta crystalline form results. Both forms have been identified in the positive plates of storage batteries.

Unless stabilizers are added, the widely used vinyl plastics (polyvinyl chloride) suffer a breakdown due to heat and light, rendering the plastic brittle and discoloured. Stabilizers take up hydrogen chloride released in the degradation. Theoretically, litharge would be a very efficient acid acceptor, but the nature of vinyl stabilization goes beyond mere acid acceptance, and various other chemical and physical actions must be incorporated into a desirable stabilizer or combination. A series of reaction products of litharge with various organic and inorganic acids are widely used as vinyl stabilizers.

Lead oxide was used as a major constituent of glass by the Chinese as early as the 6th century. The glass was strongly discoloured by impurities such as copper. The use of lead oxide in glass to achieve clarity was unknown until the invention by George Ravenscroft of English crystal, or flint glass, in 1675. Lead oxide yields a glass with a high index of refraction, which accounts for the brilliance of cut lead crystal and for its use in optical lenses. It also lends weight and resonance to the glass.

Economic importance. On the basis of tonnage of metal refined, lead is the fifth most important metal, after iron, aluminum, copper, and zinc.

World consumption of primary lead for the mid-1970s exceeded 3,000,000 tons annually, of which about 40 percent was consumed by the U.S., a third by the Soviet Union, and the remainder by the rest of the world.

World Production and Consumption of Lead,
Representative Years
(000 tons)

	world lead mine production		world refined lead production		world refined lead consumption	
	1964	1975	1964	1975	1964	1975
America	936	1,379	1,331	1,572	1,274	1,417
Europe	376	422	996	1,173	1,308	1,267
Africa	237	152	100	109	39	76
Asia	107	143	151	221	264	316
Australia	412	395	244	194	70	84
Total	2,068	2,490*	2,822	3,268*	2,955	3,161*

*Detail does not add to total because of rounding.
Source: International Lead and Zinc Study Group,
United Nations.

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(E.J.M.)

Learning, Animal

Ways of defining learning and of interpreting observed behaviour depend, in a fundamental way, on the view taken of the basic nature of the learner. Some of the difficulties in definition are considered in the article **LEARNING THEORIES**.

All living organisms adjust or adapt to changes in the stimulation they receive from their environment. In other words, they receive and store information; this is in large measure equivalent to saying that they learn. In a very limited and special sense it can be said that plants learn (insofar as they receive and store information), and efforts to distinguish between animals and plants on this basis alone are not satisfactory. Indeed, certain groups of organisms—e.g., slime molds and *Euglena*—can, at one stage of their life cycle, be regarded as plants and at another as animals. From the point of view of learning, however, the most important difference is that plants on the whole are fixed or sedentary, while animals generally are mobile and active.

Animals are in fact essentially predatory-behaviour machines that must go out and find and catch their food; or at least they must be equipped with special devices, as in so many marine organisms, for filtering food out of water, sweeping it toward themselves, and ingesting it in some form or other. This emphasis on the importance of movement in animals is absolutely fundamental. Once an animal starts to evolve movement, as distinct from being passively carried along by currents in the lake or sea or by wind, it may evolve in two directions: (1) it can either move in an entirely random manner, in which case the movement itself must bring it into contact with all that it needs (including, of course, food, oxygen, and water) and ensure normal development and survival of a sufficient proportion of the species; or (2) if such random movement is not sufficient, then there must be directed movement, which can be of many different kinds (see **LOCOMOTION, ANIMAL**). The first essential of directed movement is that there must be special devices for detecting objects in the environment that can give guidance, either direct or indirect. The more precise and elaborate these movements become, the greater will be the evolutionary pressure to develop more and more precise sense organs. If an animal is to move in a particular direction it will be able to perform much better by being elongate, perhaps to some extent "streamlined." This, of course, implies that the most acute sense organs, as well as the point at which food is absorbed, will tend to be at the front end—i.e., the animal should have some kind of "head." Even below this level of evolution, however, animals use information collected about past events as a guide to the future, evidence of having learned some of the predictable regularities in their environments.

Much of the potential for animal behaviour seems so strongly ingrained and so very little influenced by past experience that it may be called inborn, unlearned, or instinctive; that is to say, many animals are innately programmed directive machines (see **INSTINCT**). It is when organisms can perceive and change their behaviour as a result of their perceptions that they are said to learn. Learning, then, is the organization of behaviour as a result of individual experience. This definition indicates the minimum qualities a phenomenon must have in order to

be classed as an example of learning and avoids the confusion that is bound to result if an attempt is made to define the manner in which the phenomenon is brought about. Although the views as to the ways in which learning is mediated in an organism continuously change with the acquisition of new knowledge about structure and physiology, the basic idea of learning remains the same. That is to say, learning must first be defined behaviorally, after which it can be considered physiologically, when possible.

It has often been suggested that learning in general is adaptive—it manifests itself by adaptive changes in individual behaviour as a result of experience. It is true that most learning usually is adaptive in the sense that it is a mode of adjustment that enables an animal to survive. This in fact has been included in the definition, because the word organization itself implies adaptiveness in some degree. Learning is also often regarded as something that is relatively long lasting, something that has a more or less enduring effect on behaviour. Again, this fits in with the general definition of learning, but the length of its effect may vary from changes of exceedingly brief duration to changes that last a lifetime.

The following articles are related to the subject of learning in animals, including man: **BEHAVIOUR, ANIMAL**; **INSTINCT**; **LEARNING, PERCEPTUAL**; **LEARNING, PSYCHOMOTOR**; **LEARNING THEORIES**; **MEMORY: RETENTION AND FORGETTING**. This article is divided into the following major sections:

- I. Types of learning
 - Habituation
 - Associative learning
- II. Behavioral and physiological aspects of learning
 - Stimulus-response and cognitive mechanisms
 - Neurophysiological mechanisms
- III. Evolution of learning ability
 - Learning in invertebrates
 - Learning in vertebrates

I. Types of learning

HABITUATION

It is almost impossible to divide the various types of learning into categories that are mutually exclusive, that can be sharply defined, and that cover the entire range of animal learning. It is convenient, however, to start with habituation, because this phenomenon appears to be the simplest form of learning. It can be defined as the relatively persistent waning of a response as a result of repeated or continuous stimulation that is not associated with any kind of reward or reinforcement. Habituation is further characterized as being specific for a particular stimulus, and its relative permanence also distinguishes it from such temporary manifestations as fatigue and sensory adaptation (e.g., becoming oblivious to distracting sounds). Habituation thus implies a tendency of an animal merely to drop those responses that experience indicates are of no value in its life. As the simplest form of learning, habituation is quite effective in lower animals because organisms do not need more than one type of sensory mechanism to become habituated to a particular kind of stimulus. This rules out, of course, any learning by these organisms in which two or more different kinds of stimuli, received by two or more different kinds of sensory mechanisms, must be coordinated to produce either a new response or an old response in a new context.

As a form of learning, habituation is known to occur in response to all types of stimuli and in animals of all grades of organization, including the most primitive one-celled organisms (protozoans). A classic example of habituation is provided by the snail *Helix albolabris*. When the surface on which the snail is crawling is subjected to a mechanical shock, the snail immediately withdraws its tentacles for a short time. If the mechanical shock is repeated at regular intervals and if the intensity of the stimulus is maintained at a constant level, the extent and duration of tentacle withdrawal steadily decrease until the animal has become completely indifferent (habituated) to the stimulus. If, during the course of the experiment, the intensity of the stimulus is increased, the re-

Simplest form of learning